

BALL BEARING STIFFNESS. A NEW APPROACH OFFERING ANALYTICAL EXPRESSIONS

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ABSTRACT

Space mechanisms use preloaded ball bearings in order to withstand the severe vibrations during launch. The launch strength requires the calculation of the bearing stiffness, but this calculation is complex. Nowadays, there is no analytical expression that gives the stiffness of a bearing. Stiffness is computed using an iterative algorithm such as Newton-Raphson, to solve the nonlinear system of equations.

This paper aims at offering a simplified analytical approach, based on the assumption that the contact angle is constant. This approach gives analytical formulas of the stiffness of preloaded ball bearing.

Notations

a Semimajor axis of contact ellipse
 b Semiminor axis of contact ellipse
 B = $f_c + f_i - 1$ Total curvature of the bearing
 D Ball diameter
 d_m Bearing pitch diameter
 E Modulus of elasticity
 e Axial deflection due to preload
 f $f_c = r_c / D$ Dimensionless parameter
 F(x) Elliptic integral of the first kind
 K_b Ball stiffness
 k_a Axial stiffness of paired bearing
 k_r Radial stiffness of paired bearing
 PH Hertzian pressure
 P Bearing preload
 Q Ball normal load
 r_i, r_c Raceway groove curvature radius
 R_x, R_y Equivalent curvature radius
 S(x) Elliptic integral of the second kind
 Z Ball complement
 α Contact angle
 δ_a Axial deflection
 δ_n Normal approach along the line of contact
 δ_r Radial deflection
 e = 0,5 [1 + (δ_a / δ_r) tan α]
 $\gamma = D \cos \alpha / d_m$ Dimensionless parameter
 Γ Curvature difference
 $\kappa = a / b$ Elongation of elliptic contact area
 ν Poisson's ratio

$$\rho = Ry / Rx$$

1 INTRODUCTION

Preloaded angular contact ball bearings are used in several applications, submitted to severe vibrations: spindles of machine tools, gyroscopes, and space or military mechanisms. The preload suppresses the backlash, which highly improves the strength to launch vibrations, but also offers pointing accuracy. Mastering bearing stiffness allows to define the optimum preload level. A too low preload generates a high gapping under launch vibrations, which generates shocks that may damage balls and tracks. A too high preload generates a high friction torque and degrades the life duration.

Bearing stiffness calculation is usually done using an iterative algorithm such as Newton-Raphson, because the contact angle depends on the loading. There is no analytical solution giving the bearing stiffness.

The purpose of this paper is to provide with an analytical expression of ball bearing stiffness, for a preloaded paired bearing.

2 BALL STIFFNESS

The calculation of the ball stiffness is complex. It is based on Hertz theory [1]. Jones proposed in 1946 a simplified calculation [2] [7]. But it leads to an underestimated ball stiffness by 5 to 10%.

2.1 Hertz theory

Under a normal load, the contact area between the ball and the ring is elliptic. The pressure manifold is a paraboloid. The maximum contact pressure is located at the centre of the elliptic area. It is called the Hertzian pressure and is given by following expression

$$PH = \frac{3Q}{2\pi ab} \quad (01)$$

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